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DYNAMIC DISPLAYS FOR TACTICAL PLANNING VOLUME I: USER-ORIENTED DESCRIPTION

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U. S. Army
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Volume I of the three-volume set describes an exploratory application of computer graphics with animation capabilities for two-sided, user-controlled, dynamic wargaming. The description is intended for Army managers, command staffs, and other potential users of the concepts. The project emphasizes that a battlefield planner/analyst can work in harmony with computer graphics to structure and analyze battlefield situations.

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Preliminary procedures were developed that allow noncomputer personnel to create battlefield situations on displays and to assess changing events using dynamic replays and computer calculations of possible outcomes. Special displays allow the planner to see how terrain affects unit mobility and combat effectiveness. In addition, the use of dynamic replays of events and likely engagements helps the planner to interpret time and space relationships within scenarios. The aid has potential for allowing rapid evaluation of "what if?" battlefield questions. Volume II, published as ARI Technical Report 455, is intended for readers with specialized interests in research and development of interactive graphics for battlefield applications. Volume III, ARI Research Note 80-9, contains detailed documentation for systems programmers/technical personnel who are interested in specifics of implementation.

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Information Systems
and Displays

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FOREWORD

The Human Factors Technical Area of the Army Research Institute for the Behavioral and Social Sciences (ARI) is concerned with demands of the increasingly complex battlefield for improved man-machine systems needed to acquire, transmit, process, disseminate, and utilize information. The research focuses on the interface problems and interactions within command and control centers and concerns such areas as decision aids, tactical symbology, user-oriented systems, information management, staff operations and procedures, and systems integration and utilization.

One area of special research interest involves the application of automated display systems to analyze and model the dynamic battlefield. Graphic display methods, including aids and modeling concepts, potentially can enhance the ability of the command staff, at both division and corps levels, to make timely and comprehensive analyses and projections of battlefield information. The present research demonstrated how computer graphics could assist the commander and his staff in representing and interpreting the dynamic battlefield. The research is part of a continuing effort to provide the command staff with improved capability for coping with the modern battlefield's increased flow of tactical events, by developing methods using computer graphics to transmit information. Such research provides a necessary technological base for effective design of the user/systems interface.

Research in the area of graphic analysis of tactical dynamics is conducted as an in-house effort augmented by contracts with organizations selected for their specialized capabilities and facilities. These efforts are responsive to general requirements of Army Project 2Q162717A790.

The present research is also related to special requirements of the U.S. Army Combined Arms Combat Development Activity, Fort Leavenworth, Kans. Special requirements are contained in Human Resource Needs 80-307 (Optimizing Display of Topographic and Dynamic Battlefield Information) and 80-308 (Processing and Problem Solving Aids in Tactical Automated Systems).

JOSEPH ZEIDNER
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DYNAMIC DISPLAYS FOR TACTICAL PLANNING
VOLUME I: USER-ORIENTED DESCRIPTION

BRIEF

Requirement:

To demonstrate the application of computer graphics to user-controlled dynamic wargaming of friend and enemy forces.

Procedure:

Preliminary procedures were developed which allow noncomputer personnel to create battlefield situations on displays and to assess changing events using dynamic replays and computer calculations of possible outcomes. Using this system, a battlefield planner/analyst can sketch terrain (including forests, hills, cities, roads, lakes, and rivers); specify friend and enemy orders of battle; and designate unit movement paths for units or unit clusters. Special displays allow the planner to see how terrain affects unit mobility and combat effectiveness. In addition, dynamic replays of events and displays of likely engagements help the planner to create scenarios and to interpret time and space relationships within them.

Findings:

Computer graphics with animation capabilities show promise for allowing the battlefield planner to efficiently structure and analyze likely tactical events. The current effort demonstrated that an interactive system could aid the planner in representing and interpreting the dynamic battlefield.

Utilization of Findings:

The initial framework, interactive techniques, display formats, and basic algorithms provide a foundation for further development of a major battlefield planning aid at division/corps level. As an interim step, the aid's usefulness should be further developed, then evaluated, and applied to a variety of operational contexts. The aid has excellent potential for allowing battlefield planners to rapidly evaluate "What if?" battlefield questions through the use of computer graphics.

DYNAMIC DISPLAYS FOR TACTICAL PLANNING
VOLUME I: USER-ORIENTED DESCRIPTION

CONTENTS

LIST OF FIGURES

DYNAMIC DISPLAYS FOR TACTICAL PLANNING
VOLUME I: USER-ORIENTED DESCRIPTION

INTRODUCTION AND BACKGROUND

Introduction

In the future, U.S. forces are likely to face enemy tactics that stress highly mobile and mechanized forces using breakthrough maneuvers supported by massed artillery fires. To counter this threat, battlefield commanders need to make timely assessments of the situation, identify likely breakthrough point(s), and rapidly move friendly forces (anticipated to be numerically inferior) to blocking/defending positions. The pace of action and the numerous changing events will result in an enormous amount of rapidly changing information for the command staff to consider. Consequently, the command staff requires a way to quickly evaluate alternative maneuver and engagement plans in order to rapidly assess the dynamic battlefield situation and coordinate the deployment of combat and support units in both defensive and offensive action. The current work demonstrated the application of computer graphics to user-controlled dynamic wargaming of friend and enemy forces.

The command staff traditionally does battlefield planning and evaluation by "mental" wargaming and by using hand-drawn battlefield information overlayed on maps to represent changing events. However, these procedures are time-consuming for a complex battlefield, and the results do not make space-time relationships easy to visualize. The map overlays show friendly and enemy orders of battle and place a primary emphasis on major units and their positions. Potential unit movements may be indicated by arrows, and unit areas of operation (i.e., responsibility) are sometimes plotted. Since the actual situation requires examination of simultaneous movements of many units, the map overlays must be prepared in coarse time increments, or the information has to be manipulated mentally. In addition, mobility and firepower capabilities of units are obtained either from "hardcopy" reference material or are accounted for mentally. The result is a tendency to emphasize expedient procedures whose major shortcoming is a failure to use all relevant information available.

Complete automation of the commander's planning function would minimize the use of valuable judgments provided by a commander and would reduce current flexibility to respond to threats. However, the commander's performance can be enhanced greatly with semiautomated support. Given modern computer technology, we should be able to develop an interactive wargaming capability that enables the command staff to develop and analyze alternative courses of action quickly. The objective of research reported here was to investigate how interactive computer graphics could assist the user in representing and interpreting the dynamic battlefield. The result, a preliminary version of the Tactical On-Line Maneuver Model (TOMM), is documented in this report.

A 16mm film is available that highlights the use of interactive computer graphics and dynamic displays as an aid for battlefield planning and analysis.[1]

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[1]Contact ARI for further information.

Background

Operational and User Need

The operational need is for accurate and rapid evaluation of the many alternatives open to the enemy and the alternatives for friendly forces that might meet our objectives. Specifically, this includes the following estimates:

1. Where the enemy might attempt to go and with which forces.

2. How fast the enemy might reach objectives given the terrain, man-made obstacles, and friendly forces in the way.

3. How long it would take friendly forces to reach new positions.

4. Where friendly and enemy forces would be when they detected each other.

5. The areas that could be brought under fire by units from each side throughout the scenario period.

6. The likely outcomes of engagements that could take place given the movements, detection capabilities, and regions that could be brought under fire by each side.

Because of the anticipated pace of actions on the modern battlefield, the command staff needs to do all of these tasks much faster than in past conflicts.

To satisfy operational needs, the battlefield planner/decisionmaker should easily be able to represent a military situation both graphically and dynamically. Graphics provides the military planner with a map-based geographic framework that is familiar; the dynamics would facilitate understanding of the evolutionary nature of events. Basically, there should be aids for constructing a macro-model of battlefield action. These aids must take into account specific conditions and constraints and enable the following kinds of activities to be done rapidly:

1. Representation of terrain, units, and unit capabilities such as their mobility in each kind of terrain; the regions within which a unit can detect opposing forces; and the regions that a unit can take under fire.

2. Representation of intelligence data such as sightings and density of radio traffic emanating from map locations.

3. Representation of battlefield dynamics of movements and detections so that the user actually can see them instead of having to mentally visualize them.

4. Numerous and complex calculations required to accurately analyze battlefield events such as engagements.

5. Accessing stored data used in battlefield analysis so that the user does not have to look it up in tables or rely on memory.

Basically a battlefield system is needed that would enable its users to generate and evaluate alternative scenarios that contain the constraints and special conditions applicable during the planning/analysis period. This system must be configured so that it and the user can perform consistently well during a complicated planning sequence performed in a short time under a range of stressful conditions.

Interactive Graphics and Battlefield Modeling

One approach to more efficient command systems is to use dynamic displays that help the commander assess the potential effectiveness of alternative deployments of his own forces to counter expected or possible enemy movements. These displays would allow the user to conceive, construct, and synthesize information in terms of symbols and patterns. This capability most certainly should appeal to the military planner who is trained to think in terms of horizon plane unit dispositions and maneuvers.

As semi-automated displays are introduced to the battlefield, their ultimate utility will be in facilitating the coupling of combat models to the users. Combat simulation models will provide a representation of warfare to improve information utilization in planning and decisionmaking tasks. However, as these combat models gain acceptance, the prime bottleneck will be coupling the user to the combat model--the user/model interface. The availability of computer-driven, fast-refresh graphics systems will permit user interaction with and manipulation of pictures of troop movements that represent maneuvers on the battlefield. The capabilities of TOMM are based on linking computer models with graphics to aid the user in dealing with various types of mobility, multi-unit maneuvers, and inter-unit detections. TOMM provides the battlefield planner an entirely new dimension for analyzing complex multi-unit dynamic situations by potentially reducing or eliminating laborious bookkeeping functions.

Technical Context

The essencial nature of interactive graphics is the rapid generation of pictorial displays of information rather than only complex alphanumeric representations. The need for such information displays is being partially addressed bv technological advances in computer systems that focus on improving data collection, storage, and graphic capabilities. In addition, there is increasing military emphasis on the user/system interface for data access and on system capabilities to help the commander interpret battlefield data. Various systems being considered for development apply the rapid data retrieval and display capabilities of computers to battlefield problems. Most of these systems can be classified into one of three categories, as described below.

Category 1 systems are very large, time-consuming simulations that run on a computer without human interaction after the inputs are given. For example, the Command, Control, Communications, and Combat Effectiveness

(FOURCE) model[2] is a two-sided, deterministic computer game that calculates and prints alphanumeric results of division-level engagements. Systems such as FOURCE are not intended for battlefield planning because most of the decisions about "what happens next" are made by stored algorithms. There is little or no latitude for modifying the simulation to reflect situation-specific information or constraints not contained in the program.

Category 2 systems are sophisticated data retrieval systems that allow an operator to view displays of the original data or results of calculations. One example is a digital terrain model,[3] which allows users to request line-of-sight data that show what can be seen simultaneously from multiple locations. It displays results based on calculations with one of three user-selected sensors: eye-level, nap-of-the-earth (helicopters), and fixed-wing aircraft. Systems in this second category are valuable for providing facts to the battlefield planner. However, more than just facts are needed. The planner also needs to generate and evaluate hypothetical situations that could happen on the battlefield. Part of the evaluation process is understanding the dynamics of rapidly occurring movements and events. Category 3 systems address these needs.

Category 3 systems include the TOMM simulation documented in this report. Graphic displays represent terrain and opposing forces and enable the operator(s) to play the forces against each other interactively via displayed movements and engagements that are under some degree of operator control. These simulations can be considered semi-automated versions of military board games like those sold by companies such as Avalon Hill and Simulations Publications.

One notable example is the two-sided, tactical analysis game called "JANUS" (formerly "MINIJ").[4,5] JANUS is designed to explore the military utility of different tactical nuclear weapons and the doctrine and tactics appropriate for combined conventional and nuclear combat. Battlefield features and events that include terrain, unit deployment, dynamic movement of forces, detections of opposing units, and "kills" are simulated and displayed. Two players at separate work stations interact with JANUS and with one another to control the game. To begin, they independently define unit movements and nuclear artillery fire to defend a position or to take control of a position not currently held. The players then pursue their goals based on displays of

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[2] U.S. Army TRADOC Systems Analysis Activity. Command, Control, Communications and Combat Effectiveness Model Documentation. Volume II: Technical Report. White Sands Missile Range, N. Mex., October 1978. (TRASANA Technical Memorandum 3-78.)

[3] This model was developed by the U.S. Army TRADOC Systems Analysis Activity (TRASANA), White Sands Missile Range.

[4] Smith, G. C. MINIJ: A Two-Player Interaction Simulation of Mixed Conventional/Nuclear War. Lawrence Livermore Laboratory, Livermore, Calif., December 1978.

[5] Walsh, D. H., & Schechterman, M. D. An Investigation of Selected Alternative Decision Aids. Report No. 215-5, Integrated Sciences Corporation, Santa Monica, Calif., April 1979. (DDC No. AD A070524.)

unfolding activity, and the JANUS simulation makes automated decisions about the outcomes of certain events. Decisions to fire or not to fire at detected units are made without user input. However, previously planned movements are not affected by the automated detection and firing decisions. Overall, the game is a major advance in applications of computer graphics to determine requirements for weapon development and use.

Another example of an interactive graphic simulation (Category 3) was oriented toward planning intelligence data collection;[6] it was a precursor of the current TOMM work. The research showed the potential value of allowing users to conceive, construct, examine, and evaluate potential tactical events with the aid of dynamic computer graphics. However, the capability was limited to simplified intelligence collection planning and data analysis. Input techniques were developed for users to draw outlines of terrain features, set up basic orders of battle (friend and enemy), and define simple movements of units on a display. Computer processing of the user-defined activity resulted in dynamic replays of events and gave likely outcomes.

The detection and classification performance of patrol units was chosen to demonstrate the concept of using graphics as a tool for understanding battlefield activity. Users created a display of possible enemy actions over time and then plotted paths for possible friendly patrol routes. The computer contained movement/terrain mobility algorithms for guiding user-postulated movements of units; probability algorithms calculated likely detection performance of units. The research suggests that users of computer graphics can construct potential tactical events and then analyze likely outcomes by seeing dynamic replays and results of computer calculations.

Current Work

The research described in this report expanded the potential utility of computer graphics beyond the earlier effort on simplified intelligence planning and analysis. The purpose was to explore the use of interactive displays in structuring and assessing alternative reactions of friendly forces against expected or possible enemy movements. TOMM demonstrates how the user can interactively manipulate battlefield representations to test different tactics against predicted enemy actions unfolding over time. Future computer graphic systems should in part help to indicate probable effects of terrain on unit mobility and on combat effectiveness. In addition, a modeling approach such as the one in TOMM should help the user to assess probable outcomes of events and to understand critical patterns of battlefield activity. The present work was structured to evolve toward an interactive graphic system that would use battlefield models to help serve the commander's decision needs. The implemented capabilities are:

1. Terrain Realism Model. The model allows the user to define forests, hills, cities, roads, lakes, and rivers. Terrain mobility for each unit type is displayed in terms of GO, SLOW-GO, VERY SLOW-GO, and

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[6] Irving, G. W. et al. Modeling of Tactical Events by Interactive Graphics: Approach, Interface Design and System Design. ARI Technical Report No. TR-78-A40, December 1978.

NO-GO regions as a function of the movement rate for the designated unit type.

2. "Look-Ahead" Battlefield Model. This model enables the user to interactively define orders of battle for both sides, to designate a movement cluster of units, and to move the cluster according to one of several predefined rules. The user can display contours of detection and area of battlefield effectiveness for each unit type and size, based on computer calculations. In addition, the look-ahead aspect of the model has provisions for computer calculations of possible engagements and displays of results. The model and user/machine interface enable the user to request dynamic replays of events. The potential for rapidly analyzing alternative tactical situations can provide reasonable answers to "what if?" questions.

3. Battlefield Representations. This model option allows the user to display the following:

   - Static contours showing where units or unit clusters of a given size or type can reach at future times when they start from a given place.

   - Dynamic movement of a future position contour.

TACTICAL ON-LINE MANEUVER MODEL

Overview

The current division-level version of TOMM exploits the users' tactical knowledge and the computer's calculation and display capabilities. The first step in TOMM use is setting up a tactical problem by using interactive graphics to sketch relevant terrain features and to specify opposing orders of battle.[7] The planner can then create unit movements for both friendly and enemy forces over a 48-hour scenario period. Finally, TOMM provides a dynamic picture of the planner's hypothetical scenario showing unit movements and interactions. Some interactions, such as terrain mobility and unit-to-unit detections, are executed by stored algorithms. However, the user has control over many variables, including all unit movements. The fundamental principle of TOMM is that the planner and computer should work in harmony to structure and analyze battlefield situations. The concept is powerful largely because the command staff, rather than inflexible "canned" algorithms, provides the guiding intelligence.

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[7] Any one person could use TOMM, but that might not be the optimal approach. Instead, different members of the command staff could become "the user" depending on the particular task. For example, displays of terrain, terrain status, intelligence estimates of enemy forces, relevant meteorological data, and other items required for battlefield planning could be created by specialists and stored in the computer for later use by intelligence and operations personnel who typically define and analyze tactical alternatives.

TOMM was not designed as a tool for detailed battlefield analysis. Instead, it provides a way for battlefield planners to pose and rapidly evaluate typical "what if?" situations:

1. Potential meeting engagements resulting from the mobility of each side's units in the terrain, their approach paths to the meeting ground, their detection capabilities, and the departure times from present positions of all units involved on both sides.

2. Positioning of flank units to obtain reliable early warning by providing efficient overlapping detection coverage.

3. Verifying overlapping weapon coverage of units involved in coordinated maneuvers.

The concept of TOMM as a planning aid is still evolving, and the work reported here represents only some of the functional capabilities and features that such an interactive graphics system could or should have.

Typical Sequence of Operating Procedures

To use the current TOMM capabilities, a planner sits at a mini-computer-driven, four-color vector graphic display[8] and operates the system with a trackball and special function keyboard. The special function keyboard primarily allows the user to choose the interactive capabilities needed for creating a scenario and replaying it. After a capability is chosen (e.g., terrain generation, unit movements/speeds), the trackball and keyboard are used to specify shapes of terrain features, unit locations, unit movement paths, and so on.

The planner first uses the trackball and function keyboard to generate terrain and to plot both friendly and enemy orders of battle. Then, the planner defines movements of single units or groups of units by using the trackball to mark nodes on a path and the function keyboard to specify the unit's times of arrival and departure at each node. After defining movements for one side, the planner can request a dynamic replay showing the simultaneous movements of all units. This replay can be interrupted at any time to change movements so that the combined events better conform to the planner's concept of a coordinated tactic.

When the planner has finished defining movements for one side, the process is repeated for the opposing side. However, this time the simulation carried out during the replay stops each time a detection is made by one side or the other according to an algorithm that considers terrain and unit characteristics. The display shows the detecting and detected units. The planner then has an opportunity to change movements previously planned for any unit on either side.

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[8]The four colors--yellow, green, orange, and red--are created by electron beam penetration of phosphor layers.

When the planner has finished defining movements for both sides, a replay that shows all movements may be initiated. This time when detections occur, the planner decides whether engagement is likely. If the choice is made to have engagement, then the planner has to decide which units will take part. Computer algorithms have been outlined (but not programmed) to calculate the proportion of each unit's firepower that is used against opposing units and the attrition of firepower and supplies that results from engagement for each unit. At the end of a detection/engagement period, the planner has an opportunity to redefine movement for any unit.

Ultimately, the planner completes all changes and is satisfied that the movements and detections represent what would be likely to happen if both sides pursued the coordinated tactics specified. This entire process constitutes creation and analysis of one hypothetical tactical situation. The planner may then wish to construct and analyze other hypothetical situations.

Functional Capabilities

Terrain Model and Order of Battle Representation

The TOMM user can create (or copy from a map) with display hardware and software the following types of terrain:

- Clear areas,
- Forests,
- Inner hill/outer hill regions,
- Cities,
- Lakes,
- Rivers, and
- Roads.

Rivers appear on the display as lines, and roads appear as parallel lines; all other types are represented as closed contours. Hills are differentiated into inner hill contours and outer hill contours as shown in Figure 1. The inner hill region represents hilly and irregular terrain that cannot be seen from points outside the outer hill contour. Conversely, a unit that is entirely within an inner hill contour cannot see terrain outside that contour. The contour region between the outer and inner hill represents the forward slopes of a hilly region. The outer hill contour defines the curvature of these forward slopes; thus point A in Figure 1 cannot be seen from point B because the view from B is blocked by the inner hill region. TOMM also "recognizes" hybrid terrains composed of (a) forest and inner hill contours and (b) forest and outer hill contours.

Terrain, as currently defined, has specified effects on unit mobility, detection, and area of battlefield effectiveness. The data on maximum speeds in terrain types and detection distances were developed after consulting experienced Army officers. The data on area of battlefield effectiveness distances for direct and indirect fire were taken (and, in some cases, extrapolated) from Army field manuals.[9,10] These data are all based on friendly

[9] U.S. Army Field Manual 105-5, Maneuver Control, Appendix G.

[10] U.S. Army Field Manual 100-5, Operations, Chapter 2.

doctrine, but changing them to more realistic numbers (for friendly and enemy forces) is a matter of changing numbers in computer reference tables. In addition, terrain definitions may readily be modified to incorporate changes in doctrine, unit capabilities, and weapon performances.

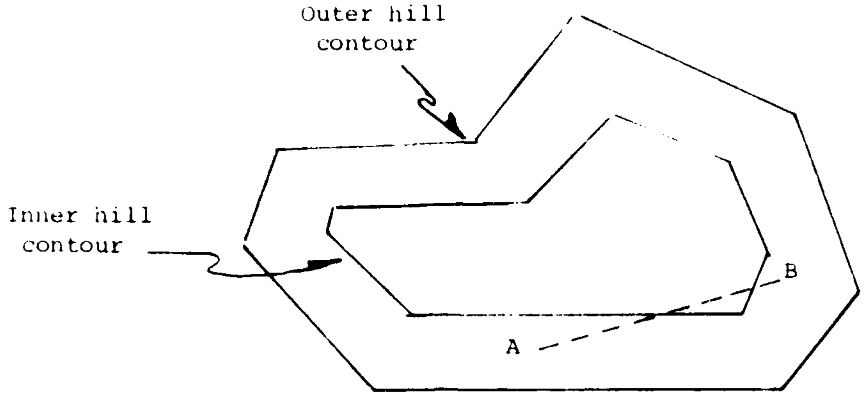

Figure 1. Representation of hills by inner and outer hill contours.

Mobility. Each unit type has a maximum allowable speed for each terrain type. The maximum speed for a battalion of a particular type is 80% of the maximum for a company of the same type; the maximum speed for a brigade is 80% of the maximum for a battalion. Lakes are not traversable; rivers are not fordable except where a road crosses a river.

Detection. The distance that a unit of any type can see within or between terrain areas varies with terrain types.

Area of Battlefield Effectiveness. Terrain affects the area that is within each unit's field of direct fire; indirect fire weapons cannot be used effectively from inside a forest.

Force Capability Representation

TOMM accounts for each unit's ability to move, to detect opposing units, and to engage in combat. This subsection describes how TOMM represents these capabilities to the user.

Terrain Mobility. Terrain types are classified as GO, SLOW-GO, VERY SLOW-GO, and NO-GO for each unit type according to a set of rules. Mobility in kilometers per hour (km/h) for each unit type in each closed contour terrain type (i.e., all terrain except roads and rivers) can be displayed at the user's request. Figure 2 illustrates a terrain mobility display for artillery units. Roads are shown in the figure as parallel green lines and

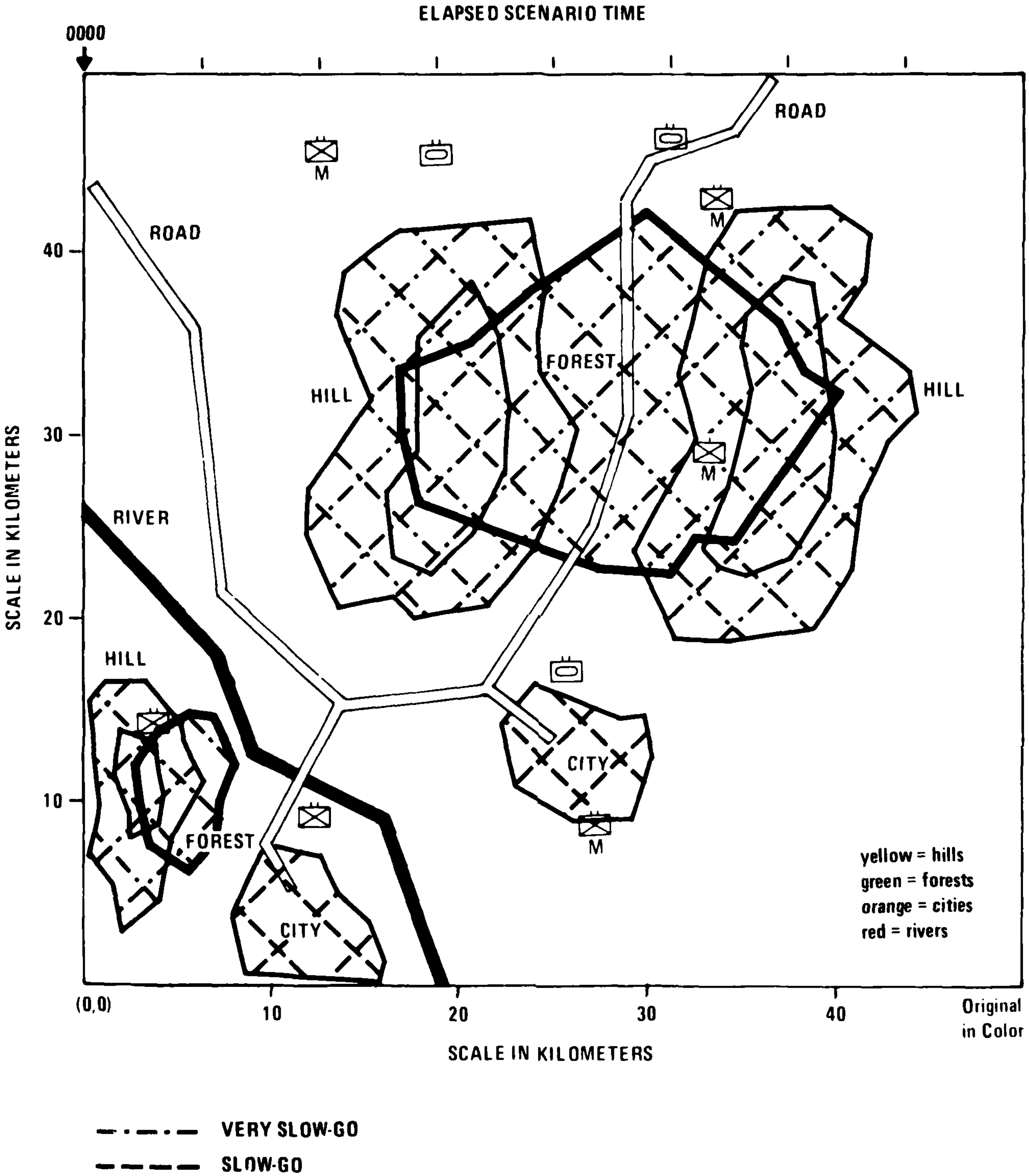

Figure 2. Mobility illustration for artillery units.

forests as dashed green contours. Hills are in yellow, cities in orange, and a river is shown in red.

Future Position Contours. The planner can call for contours representing the potential future locations and arrival times of one or more designated units. The contours take into account terrain mobility for the designated unit types and sizes. Figure 3 illustrates how contours requested by a planner appear. Assume that the planner is concerned with possible threats to the city in the lower central part of the figure. The planner hypothesizes that the threat may come from an enemy motorized infantry unit located in the hilly terrain near the top of the figure. Therefore, the planner wants to know how soon the enemy unit could reach the friendly unit, which routes the enemy unit might take, and where it could be at intermediate times between movement start and finish. The contours provide these data. Note that the latest contour passes through a friendly position. This occurs because the planner chose that location as the "destination."

Unit Movements. The planner can use display hardware and software to draw unit movements and specify unit speeds, for single units and for groups of units. Movement paths remain on the display until the planner has finished defining movements.

For movements of a group of units, the planner designates which units will form a cluster and where its center is. The planner then specifies the path and movement speed for the cluster center. An algorithm calculates and displays the specific movements for each unit. The planner can specify four types of cluster movements:

- Direction-dependent movement,
- Fixed-point-dependent movement,
- Column movement, and
- Bounding overwatch.

Direction-dependent movement allows units to maintain the same distance from a designated formation center and the same relative bearing from the direction of motion throughout a maneuver. This formation is applicable when a commander wants to be prepared for a meeting engagement throughout a maneuver and therefore wishes to maintain a fixed position among units, the formation center, and the direction of movement.

A fixed-point-dependent movement is designated to keep the positions of units relatively constant with respect to a reference point. In practice, this is equivalent to keeping two units in position relative to a third one. For example, as a potential threat location moves in relation to an infantry unit, an armor unit between these two also will move, thus maintaining the spatial relationship among the three elements.

A column movement is based on the path of a lead unit. An algorithm maintains inter-unit distances during movement and controls both on-road and off-road columns.

Bounding overwatch as implemented in TOMM is a type of column movement executed by just two units of the same type and size. This type of movement is appropriate when a commander anticipates engagement. Bounding overwatch

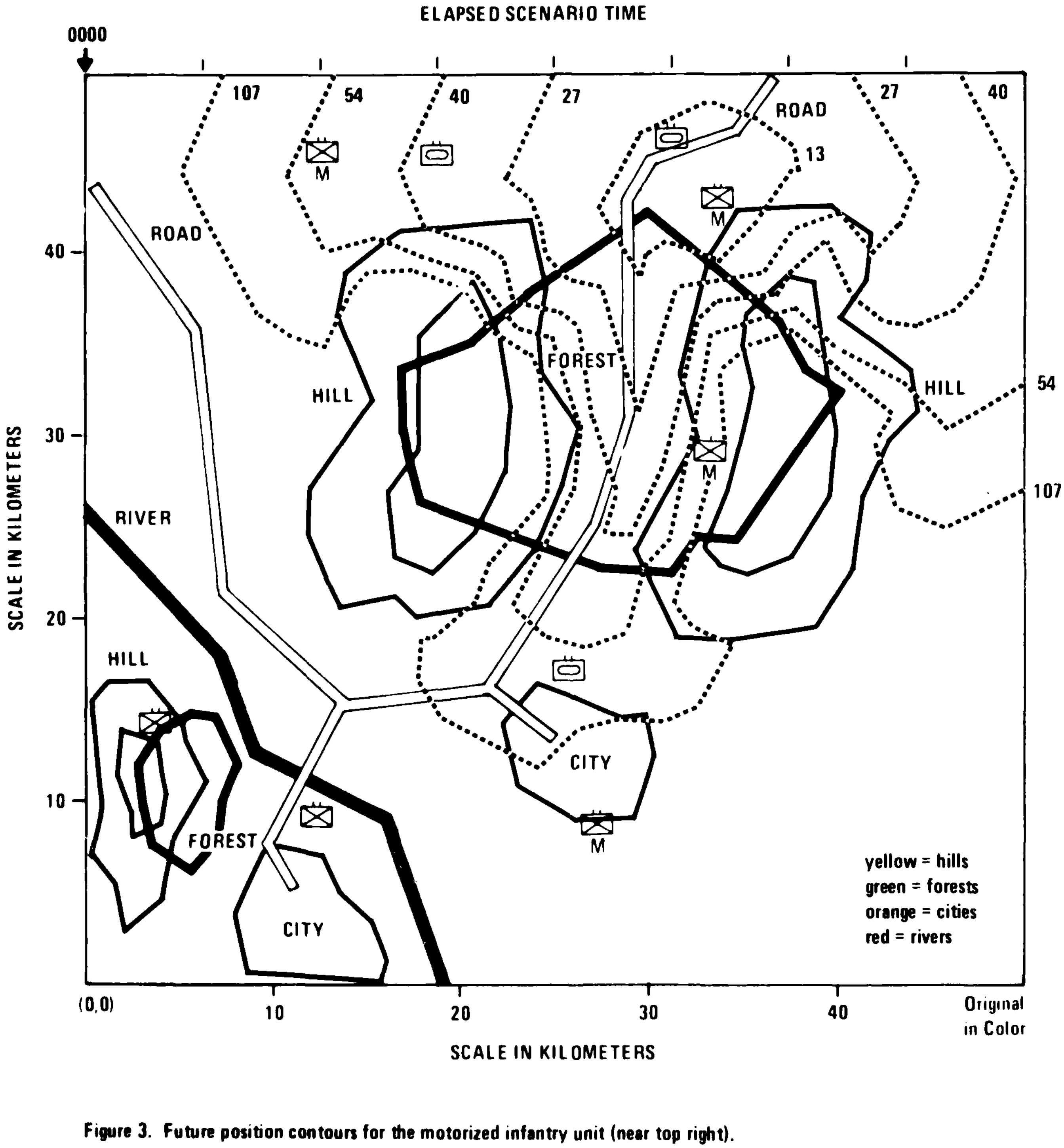

Figure 3. Future position contours for the motorized infantry unit (near top right).

enables the force to keep one unit (overwatch) stationary and the region ahead covered with its weapons while a second unit (bounding) moves up.

Detection Region. The planner can designate an x,y location and call for a display of the region within which other units will be detected on a line-of-sight basis from that location. Figure 4 is an example of this display for the infantry battalion at the lower left. The detection region is shown as a contour of the same color as the unit's symbol.

Area of Battlefield Effectiveness. The planner can designate an x,y location and call for a display of the regions that a unit at that location can place under direct and indirect fire. The direct fire region is limited to line of sight, whereas the indirect fire region is circular, as shown in Figure 5. In general, the color of areas is outlined in the same color as the unit's symbol.

Force Interaction Models

Detection. Deterministic rules automatically define when one unit can detect another; actual detections are under planner control because the planner decides all movements. (Planning is a circular process because movement decisions are influenced by consideration of where opposing units would be when a detection is made.) The detection model accounts for the following:

- Size of each pair of opposing units. (The area occupied by a unit varies with its size, and the model considers this area when calculating whether a unit can see another unit.)
- Type of terrain where each unit is located.
- Distance between each pair of opposing units.
- Whether or not unit A, which is a candidate for detection by unit B, is moving.

The detection model looks at the positions of all pairs of opposing units every 5 minutes of scenario time. When a detection occurs, the symbols of the two units involved flash on the display, and a flashing solid line connects the two units. The color of the flashing solid line indicates the nature of the detection:

1. A flashing green line indicates that the friendly unit has detected the enemy unit.
2. A flashing red line indicates that the enemy unit has detected the friendly unit.
3. A flashing orange line indicates that the enemy and friendly units have detected each other simultaneously.

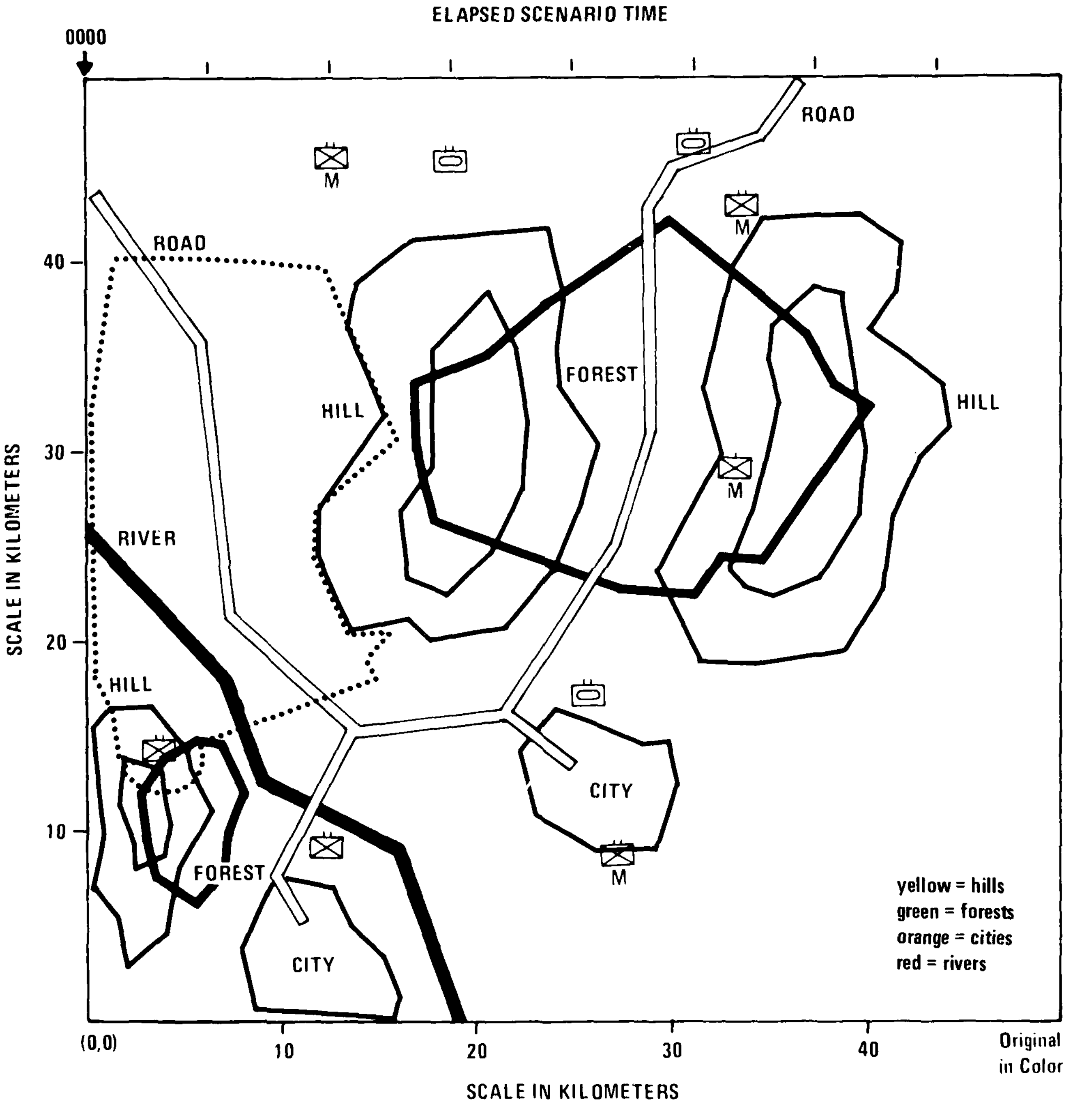

Figure 4. Line-of-sight detection region for infantry battalion (lower left corner).

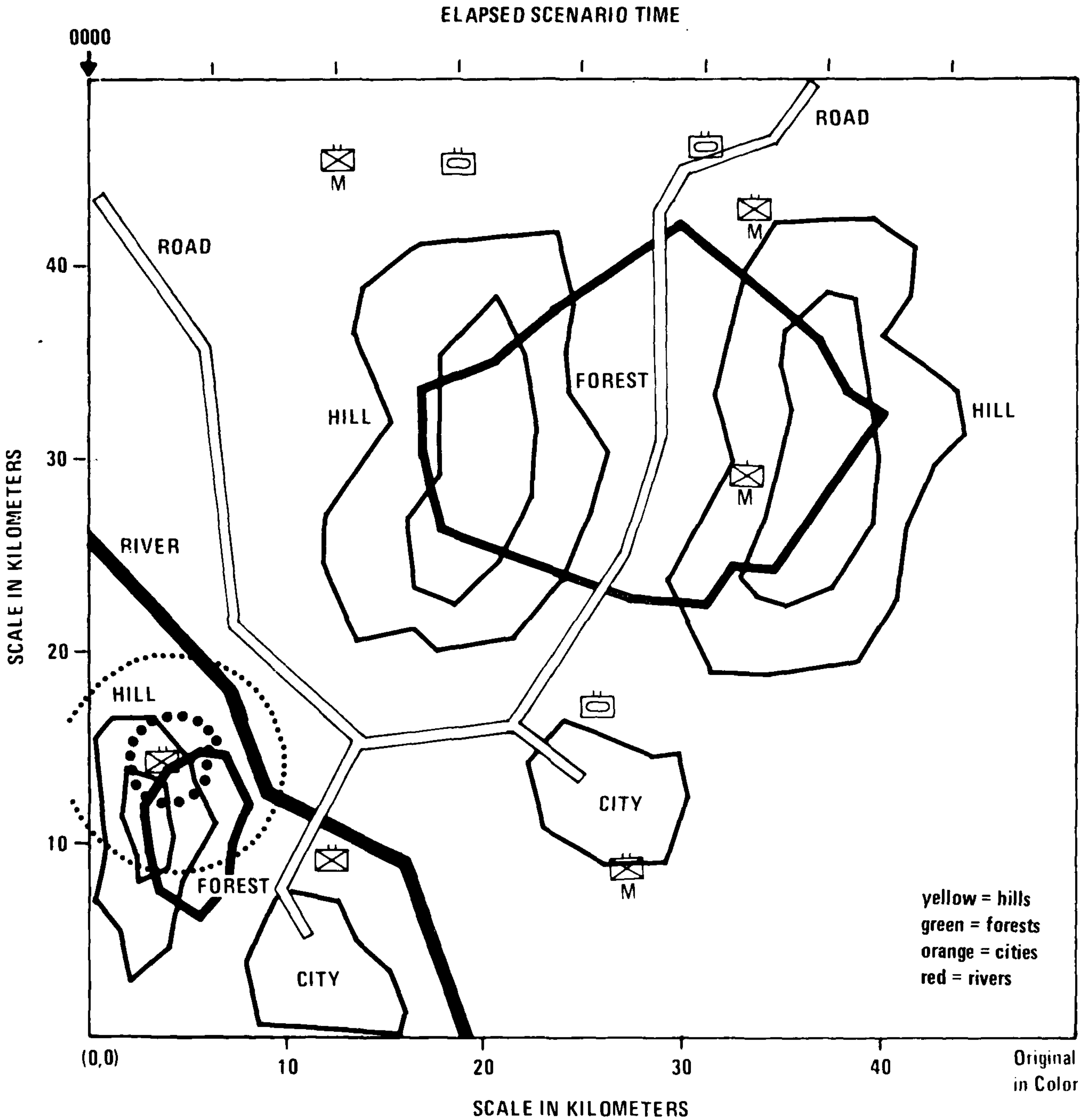

Figure 5. Area of battlefield effectiveness for infantry battalion (lower left corner).

Engagement.[11] TOMM is designed to permit the user to obtain predicted nominal outcomes of complex unit-to-unit engagements that may occur when opposing forces come within the areas of each other's battlefield effectiveness. After the user structures combat between single units and groups of opposing units, a deterministic model predicts outcomes.

A set of firepower allocation rules is available when two or more units are engaged on either side. These rules determine how much of unit A's firepower is allocated to each of the opposing units within A's area of battlefield effectiveness. The allocation rules are based on two general guidelines:

1. A unit receiving fire recognizes the amount of fire being received but does not know the strength (company, battalion, or brigade) of the firing unit.

2. A unit, receiving fire from one or more opposing units and capable of firing at more than one unit, takes into account the amount of fire it is receiving when allocating its own fire.

The basic combat effects are computed over the problem time using unit firepower and unit endurance rate algorithms. Firepower defines the ability of a unit to inflict damage on another unit, and endurance defines the ability of a particular unit to continue operations (both combat and noncombat). The engagement model also allows the designated mission (e.g., attacking; defending) of the combatants an element of surprise: ambushing units have an initial period of unopposed fire.

The model uses stored values of specific unit capabilities (e.g., detection areas and weapon ranges). These values may be changed to reflect new data on the relative performance of the types of combatants included in the TOMM scenarios. The engagement model displays estimates of declining combat potential (i.e., firepower and endurance) of the individual engaged units. This not only permits the planner/analyst to see the predicted ultimate outcome of a particular battle, but also presents the opportunity to determine possible times when friendly forces should break contact or might require reinforcements. The use of this particular engagement model would not limit the usefulness of TOMM because other combat results algorithms easily could be substituted.

Operational Overview

To use the preceding sequence of procedures and functional capabilities of TOMM, five major modes of operation are provided:

1. Structuring battlefield situations,
2. Display of battlefield information,
3. Parameter entry,

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[11] The engagement model is the only module of TOMM not yet programmed. It was included as part of TOMM's original planning and is fully described in Volume II, published as ARI Technical Report 455.

4. Replay, and
5. Executive.

The Structuring Battlefield Situations Mode allows the user to define terrain, order of battle, and unit movements and to decide whether an engagement is to occur after a detection. The user in the Display of Battlefield Information Mode can request the following displays:

- Terrain mobility regions,
- Future position contours,
- Line-of-sight detection region, and
- Area of battlefield effectiveness.

Parameter Entry Mode is needed to specify a terrain type, a unit type or size, a movement speed, or a number such as a time within a previously defined scenario. The Replay Mode displays a simultaneous, movie-like replay of all movements that have been defined and the detections that would result from these movements.

Three options that are not part of the planning or replay processes are collectively called the "Executive Mode." The Store Scenario option stores for later use all the planner inputs and events to date: terrain, orders of battle, movements, detections, and engagements. The Recall Scenario option recalls a previously generated scenario that the operator wishes to review or modify. The Exit option decouples the operator and the TOMM program in the computer.

Overall, the user/machine interface is designed to simplify the operator's use of the many capabilities in TOMM. Design features include:

1. Messages and prompts that indicate the next step the operator must take after a specific key on the function keyboard is selected.

2. A menu system for selecting parameter entries.

An example of the operator's steps during terrain definition is included in the appendix, and detailed specifications are available in ARI Technical Report 455.

FUTURE DIRECTIONS

Extension and Evaluation of TOMM's Capabilities

TOMM provides the initial framework, interactive techniques, display formats, and basic algorithms that could be developed into a major tool to aid battlefield planning. As an interim step, further work should address extensions of TOMM's capabilities so that a user can play more realistically through a scenario and see its unfolding results. In addition, TOMM's usefulness should be evaluated to determine more about the military considerations and human factors principles underlying the concept.

Priority in expanding TOMM should be given to enhancing its combat capabilities and the user's options to manipulate them; for example:

1. Incorporate data on Soviet forces for unit levels, movements, and firepower capabilities.

2. Implement the engagement model that already has been developed. This involves translating into operational software the models for allocating a unit's firepower among multiple opposing units and for calculating attrition to each engaged unit's firepower and supply endurance.

3. Enable the operator to designate a unit's combat posture at the beginning of a scenario and to change combat posture at any later scenario time.

4. Develop displays that the operator can call to see a unit's status at any time. This would include the following alphanumeric displays:

   - Symbol for the unit's type and size,
   - Label for a specific unit of a given type and size,
   - User-designated mission, and
   - Percentage of full-strength firepower and supply endurance remaining.

   Also included would be graphic displays showing percentages of full-strength firepower remaining at x equally spaced times in the most recent y minutes of a scenario.

Evaluation of TOMM should answer questions such as: (a) How helpful is this type of interactive graphics application for structuring and solving typical battlefield planning questions? (b) Which kinds of modifications should be made to existing TOMM models and displays of battlefield capabilities and analysis results? (c) Which changes should be made to the user/machine interface and interaction procedures to make TOMM easier to use? (d) Given time constraints, are planners willing and able to use TOMM?

Several kinds of testing could be done to evaluate TOMM. One level of testing could determine the value of TOMM's various graphics features including battlefield sketches, interpretive displays (e.g., unit mobility contours, unit area of battlefield effectiveness), and dynamic replays. A second level of testing could consider how complex displays and algorithms should reasonably be for rapid battlefield contingency planning. Overall, the concept of TOMM should be validated by research to determine its most useful characteristics for emerging automated battlefield systems.

Data Issues

As current TOMM capabilities were being developed, various questions arose about which data were available to provide appropriate displays for battlefield planners. For example, one issue was how to determine the approximate area occupied by a unit as a function of the unit's size, type, and mission and the terrain it occupies. These data are used to calculate

the unit's ability to detect other units, its detectability by other units, and the regions it can take under fire. Data are available for unit areas of influence and larger areas of interest. However, data about a unit's characteristics under representative combat conditions could only be derived from subjective judgments of experienced Army officers. A related issue was how to geometrically represent the area occupied by a unit. Alternatives included circles, rectangles, and ellipses. Circles were chosen because they are simplest to draw and do not require orientation along an axis. However, ellipses may be a more realistic shape for unit area. Information is needed on the degree of realism in unit representation the command staff must have in TOMM's type of planning displays.

Obtaining firepower data for estimating outcomes of unit-to-unit combat is also a problem. The data in standard Army field manuals apply to unobstructed terrain and are given in terms of individual weapon ranges and total unit firepower as a function of range. There do not appear to be any data on the predicted effectiveness of a given unit's firepower for obstructed terrains (e.g., hills, forests, and cities). Available firepower data provide no more than a starting point for calculations in TOMM that will help the command staff approximate combat outcomes. Perhaps guidelines for firepower effectiveness in alternative terrains can be developed for future use.

Data on how to model a unit's detectability, given its size, type, mission, movement speed, and terrain, were also not readily available. Based on judgments from experienced Army officers, parameters were developed and used in conjunction with a deterministic model where the result is never in doubt. That is, if the region in which an opposing unit A is considered detectable overlaps the line-of-sight detection region for unit B, then A is detected by B. In reality, however, detection is a stochastic process in which A detects B a percentage of the time when certain conditions occur. The question is whether a probabilistic model of detection would be more useful for evaluating scenario outcomes than the deterministic detection rules currently used in TOMM.[12]

Future Display Considerations

Although TOMM currently contains several innovative ideas for using interactive computer graphics in battlefield planning and analysis, other capabilities have future promise. Overall, the battlefield area being simulated should be increased to about a 150-kilometer square so that second echelon and support units could be represented as necessary. This could be done by using the display as a "window" to show different parts of a large battlefield area (at the user's request) without sacrificing display detail. In addition, provisions should be made to help the user define terrain. One way would be for the computer to draw a low-intensity grid in the display whenever the user is defining terrain with the aid of a map and reconnaissance data. Another solution to representing terrain, of course, is to store adequate digital representations in the computer. The improved battlefield representation then could be linked with displays that would further enhance TOMM's

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[12] Application of detection rate theory from sonar and radar technology could provide a useful alternative to deterministic detection.

realism. For example, methods could be developed to allow for simulation and display of:

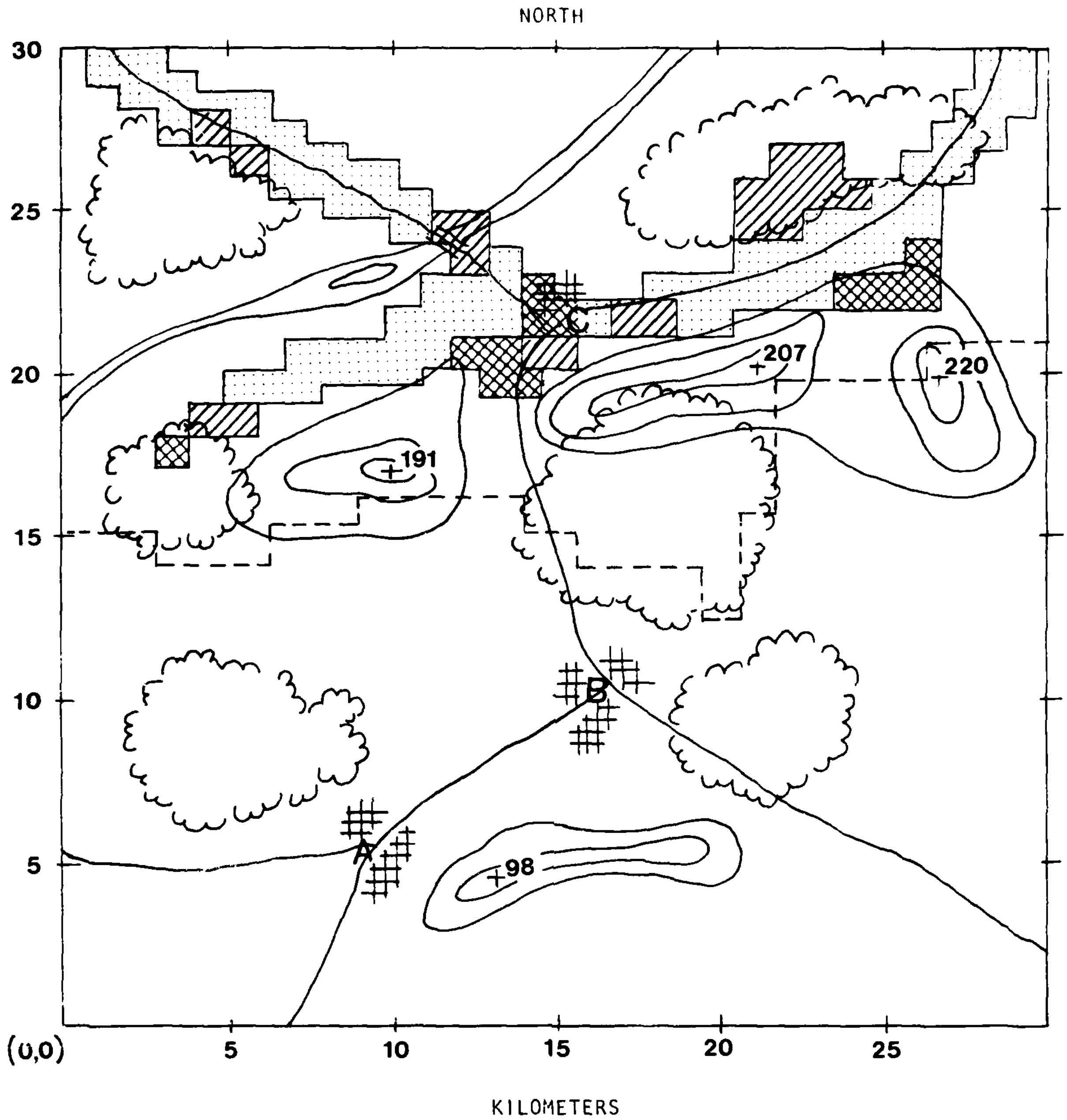
- Smoke, the changing areas affected by it, and its impact on unit movements, detections, and engagements.
- Minefields and their effects on unit movements.
- Additional unit types, such as helicopter-borne infantry and tactical airpower along with their movement characteristics, combat effectiveness, etc.
- Cluster movements for units in a line-abreast formation.

Some display capabilities that could be added to TOMM would require real-time data from the C^3I systems. For example, intelligence data could be used for the kinds of data displays shown in Figures 6, 7, and 8. They would allow the planner to estimate an enemy's intentions and future movements. These estimates would be difficult without such displays. These enhancements of TOMM, however, are further in the future than those previously described because they require interfacing appropriate data sources to TOMM.

Implications for Future Battlefield Planning and Training

An interactive planning aid to satisfy needs described in the preceding sections could be used in the field as part of the Command, Control, Communication, and Intelligence (C^3I) systems assigned to division and corps command staffs of the future. Inspection and review of battlefield data can be done by accessing for analysis friendly and enemy force data as well as intelligence files depicting unit numbers, types, dispositions, and supply levels. By representing complex dynamic patterns of enemy actions, TOMM can be used to predict enemy actions. Inspection and review of battlefield data and prediction of enemy actions can be combined as inputs with our own military objectives. TOMM can then be an aid to planning alternative actions for friendly forces, analyzing actions, and adopting a set of them as the basis for an operational battle plan. Finally, TOMM can be used to replay the major conclusions about battlefield operations for command staff sections and the unit commander. This would enable everyone connected with battlefield planning to understand changing situations quickly and make recommendations accordingly.

TOMM can also be used to communicate plans among units on the battlefield. Using the battlefield C^3 data link, the TOMM-generated operational plan can be transmitted to a higher level headquarters for rapid review/approval. TOMM would also be an efficient means of transmitting a dynamic and graphic version of tentative plans and/or battle orders to lower echelon units. One readily can visualize a commander transmitting over high-speed communication lines a major portion of a forthcoming tactical plan in the form of a dynamic display or movie-like representation of friendly movements and anticipated enemy movements. This efficient means of communication would allow rapid review, comment, and ultimate dissemination of the plan.



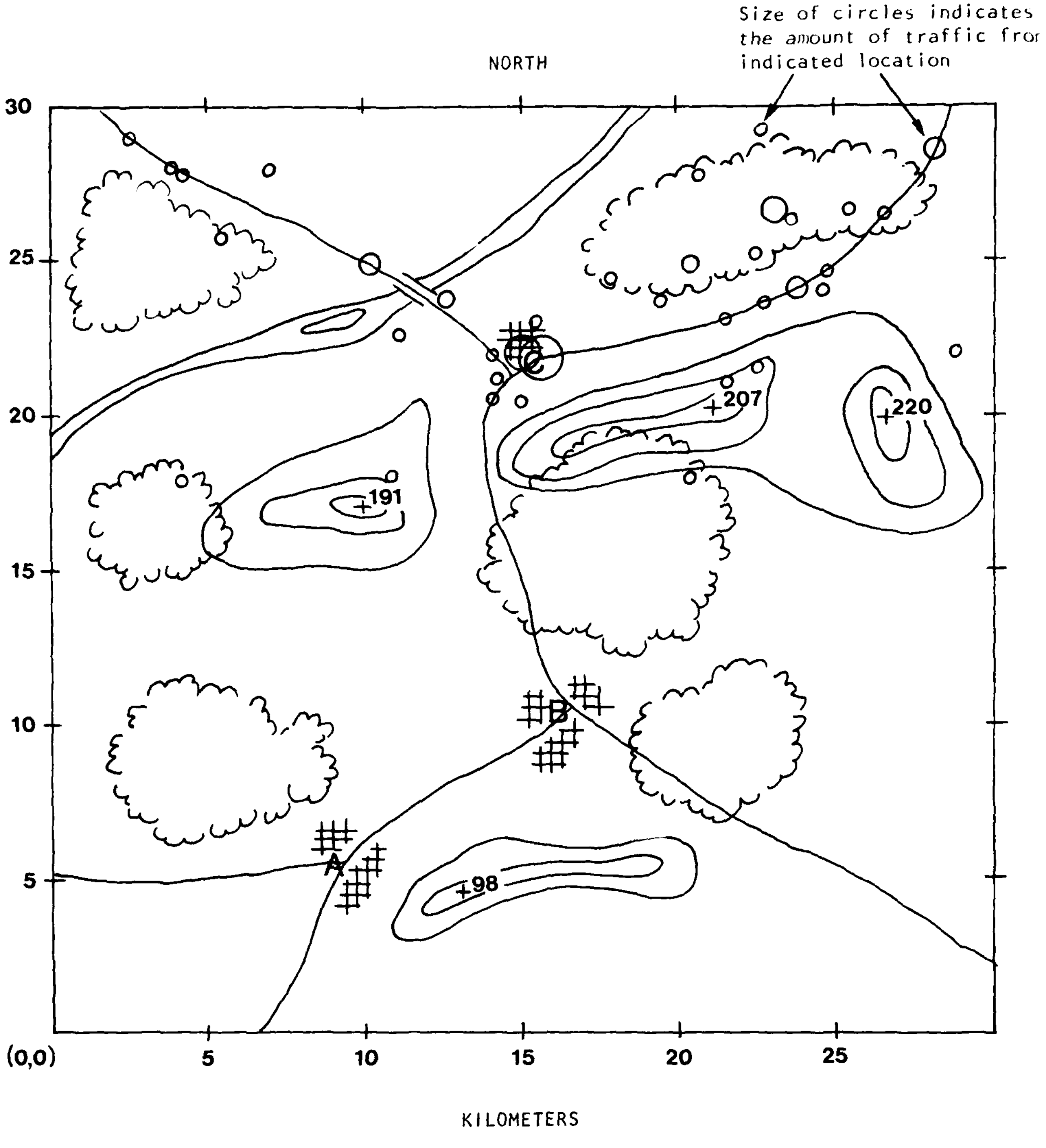
Computer Query:

"By the Density of Combat Vehicle Sightings/Sensings, Display the Data File Contents for the Last Six Hours"

KEY:

- Heavy (Sightings/Time Period)
- Moderate (Sightings/Time Period)
- Light (Sightings/Time Period)
- Sporadic or None
- Boundary of Sensed Activity

Figure 6. Display of frequency data.

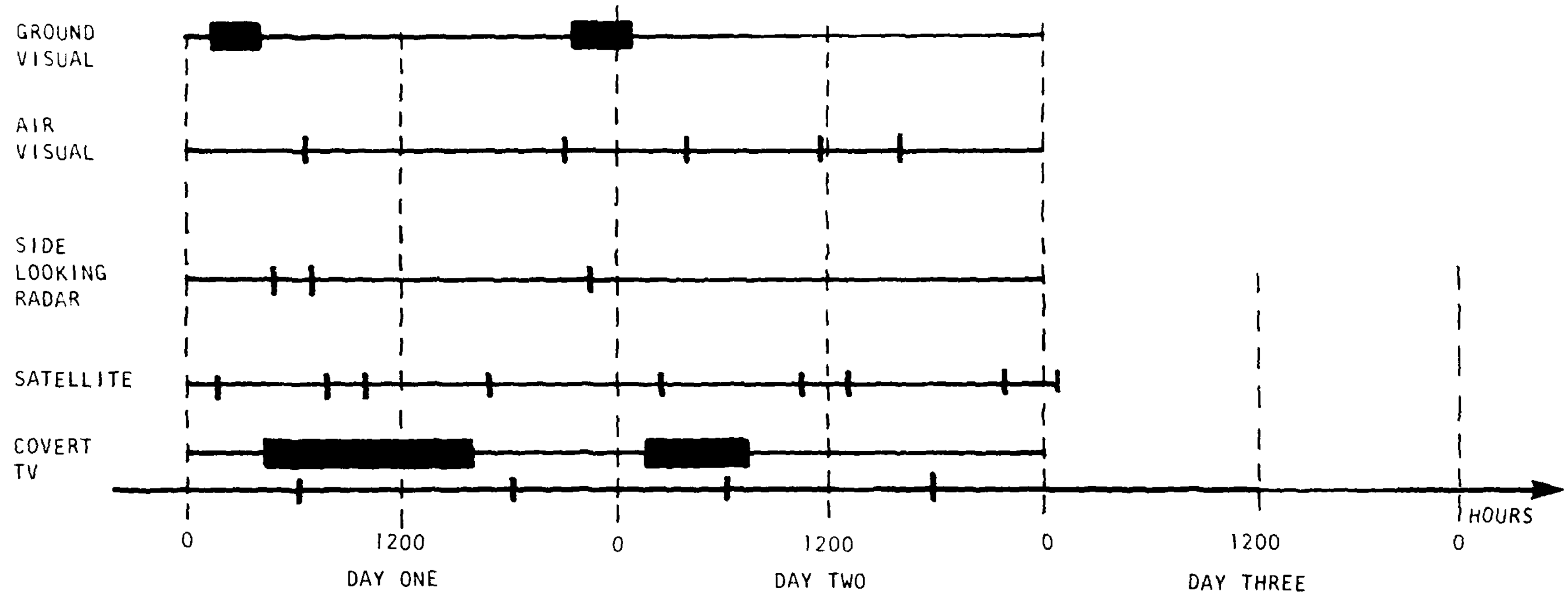


Computer Queries:

"Display the Cumulative Radio Traffic Intercepts Between 0000 Hours Day One and Now"

"Time Sequence The Previous Data"

Figure 7. Fast time replay of radio traffic intercepts.



Interrogation Time: 0030 Hrs Day Three

"*Display the time period* when the just-defined region has been under visual imaging surveillance during last 48 hours." (Operator previously used a display peripheral to bound *a rectangular region in the northwest-to-southeast orientation* including the road out of Charlieville *to the northwest.*)

Figure 8. Display of time windows when visual imaging surveillance was done in a designated region.

For command staff training, both in the field and the classroom, the graphic-based aid would allow realistic simulations for review. As the individual unit command staffs create, analyze, and communicate battlefield tactical situations, their "solutions" can automatically be recorded for both real-time evaluation and postexercise analysis. In the latter mode, it would be a simple matter to reconstruct (again on the same planning aid system) the exact sequence of events, showing the following for each participant:

- Which data were received and when.
- Which alternatives were considered and omitted from analysis.
- Which hypotheses were the basis for own-force planning.
- Which orders and requests were transmitted between the participating units.

Such information can be presented along with the events of the "real world" to permit the participants to readily evaluate their own actions and derive insights for improving future performance. In summary, the TOMM concept is ideally suited for helping the command staff's interactive wargames of friendly and enemy forces called for by a training scenario or required by real-world events.

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APPENDIX

EXAMPLE OF OPERATOR PROCEDURES DURING TERRAIN DEFINITION

The following prompt and menu appear on the display to the left of the scenario when the operator selects DEFINE TERRAIN on the function keyboard:

"SELECT A TERRAIN TYPE

Road
River
Lake
City
Hill
Forest

RETURN WHEN COMPLETED"

Small lights appear only beneath the ACCEPT, REJECT, and RETURN keys. The operator selects a particular terrain type by indexing a small circular cursor down the menu. Each time the REJECT key is pressed, the cursor moves to the next entry. Pressing the ACCEPT key tells the computer which terrain type will be drawn. If the operator selected "City," then the following message appears:

"CITY Construct contour with trackball and accept key."

The ACCEPT key is the only lighted key at this time. The operator draws each line segment of the contour and presses the ACCEPT key at the end of each segment. When the city contour has been closed, the following message appears:

"ACCEPT/REJECT FEATURE"

At this time only the ACCEPT and REJECT keys are lighted. If the operator selects ACCEPT, then the city contour is stored as part of the terrain. If the operator selects REJECT, then the contour is not stored and it disappears from the display. In either case the operator next sees the original message ("Select a Terrain Type") and the terrain menu. When the operator has finished defining all terrains, the RETURN key takes the program out of the terrain definition phase and allows use of other TOMM functional capabilities.

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1 USA ENGINEER SCHOOL LIBRARY AND LEARNING RESOURCES CENTER
1 USA ARMOR SCHOOL (USARMS) ATTN: LIBRARY
1 ORGANIZATIONAL EFFECTIVENESS TNG CEN + SCH ATTN: LIBRARIAN
1 US ARMY INTELLIGENCE CENTER + SCHOOL ATTN: ATSI-TD
1 US ARMY INTELLIGENCE CENTER + SCHOOL ATTN: ATSI-RM-M
1 US ARMY INTELLIGENCE CENTER + SCHOOL ATTN: ATSI-TD-LD
1 US ARMY INTELLIGENCE CENTER + SCHOOL ATTN: ATSI-CD-CS-C
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